

# LC Muon System R & D

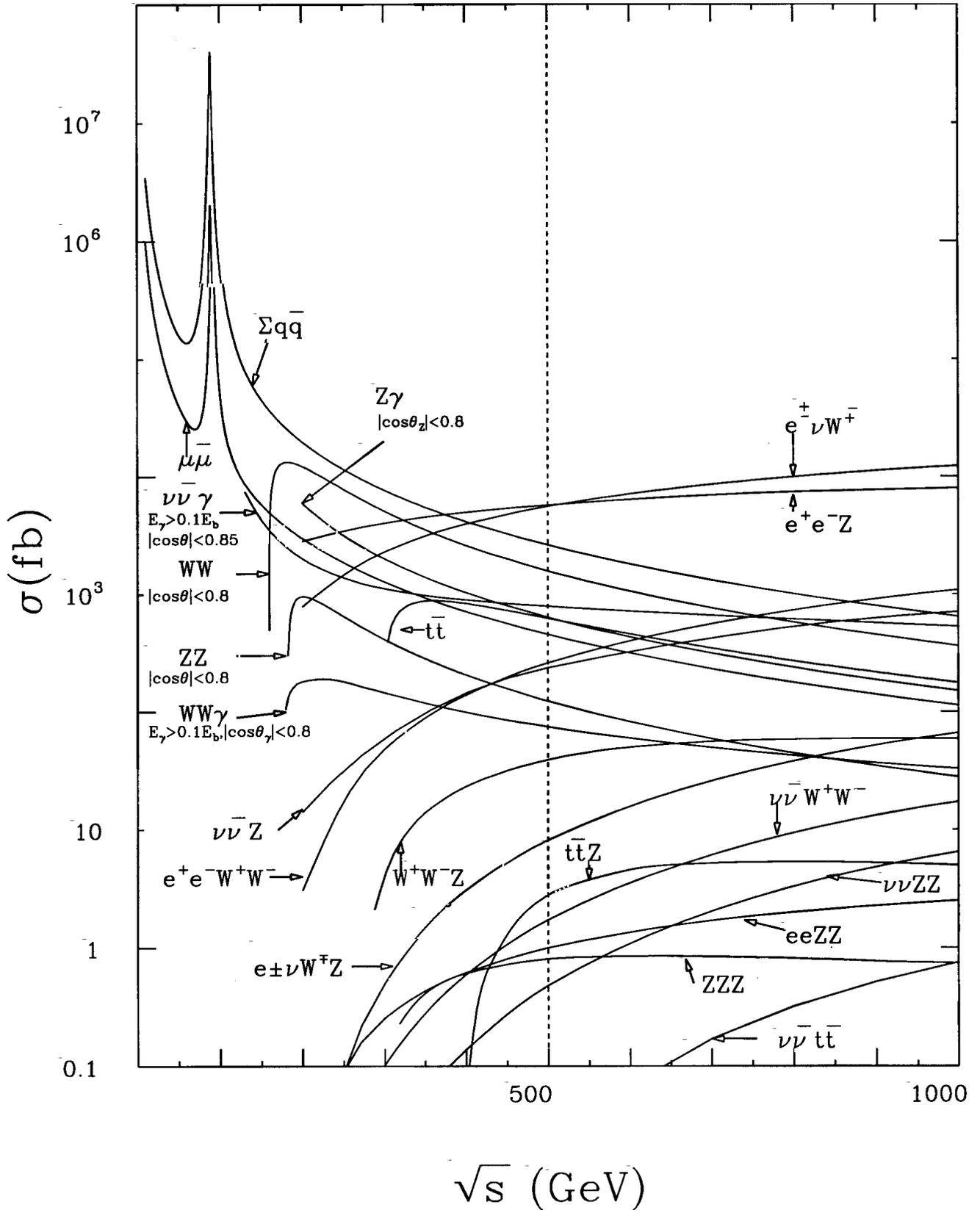
- Sources of Muons
- Muon System Specifications
- Example Muon Systems
  - RPC Detector Studies
  - Scintillator Detector Studies
- R & D Issues
- How you can get involved

Gene Fisk      April 5, 2002  
R&D Opportunities for the LC

# Sources of Muons

- Conventional EW Physics
- New Physics
- Beamline Muons

# Cross sections



# Conventional Physics - Muon Sources

Final State	500 GeV		1000 GeV	
	$\sigma(\text{fb})$	$\sigma^* \text{BR}(\text{fb})$	$\sigma(\text{fb})$	$\sigma^* \text{BR}(\text{fb})$
$e^+ \nu W^\mp$ $e^+ \nu \mu^\mp \nu$	5,640	625	12,400	1,380
$e^+ e^- Z$ $e^+ e^- \mu^+ \mu^-$	5,900	200	8,100	275
$q \bar{q}$ $b, c$ $\mu$	2,700	180	660	22
$WW$ $q \bar{q} \mu \nu$	1,660	50	360	76
$t \bar{t}$ $W^+ b W^- \bar{b}$	565	215	180	68
$\mu \mu$	435	435	115	115
Totals	16,900	2,005	21,815	1,936

$$\int l dt = 10^{34} \text{ cm}^{-2} \text{ s}^{-1} * 10^7 \text{ s} = 100 \text{ fb}^{-1}$$

$$\Rightarrow 200 \text{K } \mu\text{'s per year}$$

# Higgs Production

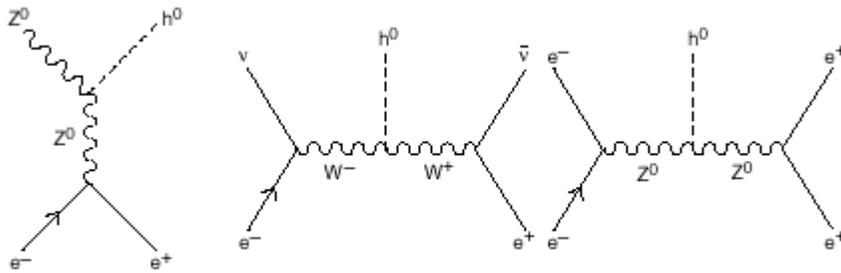
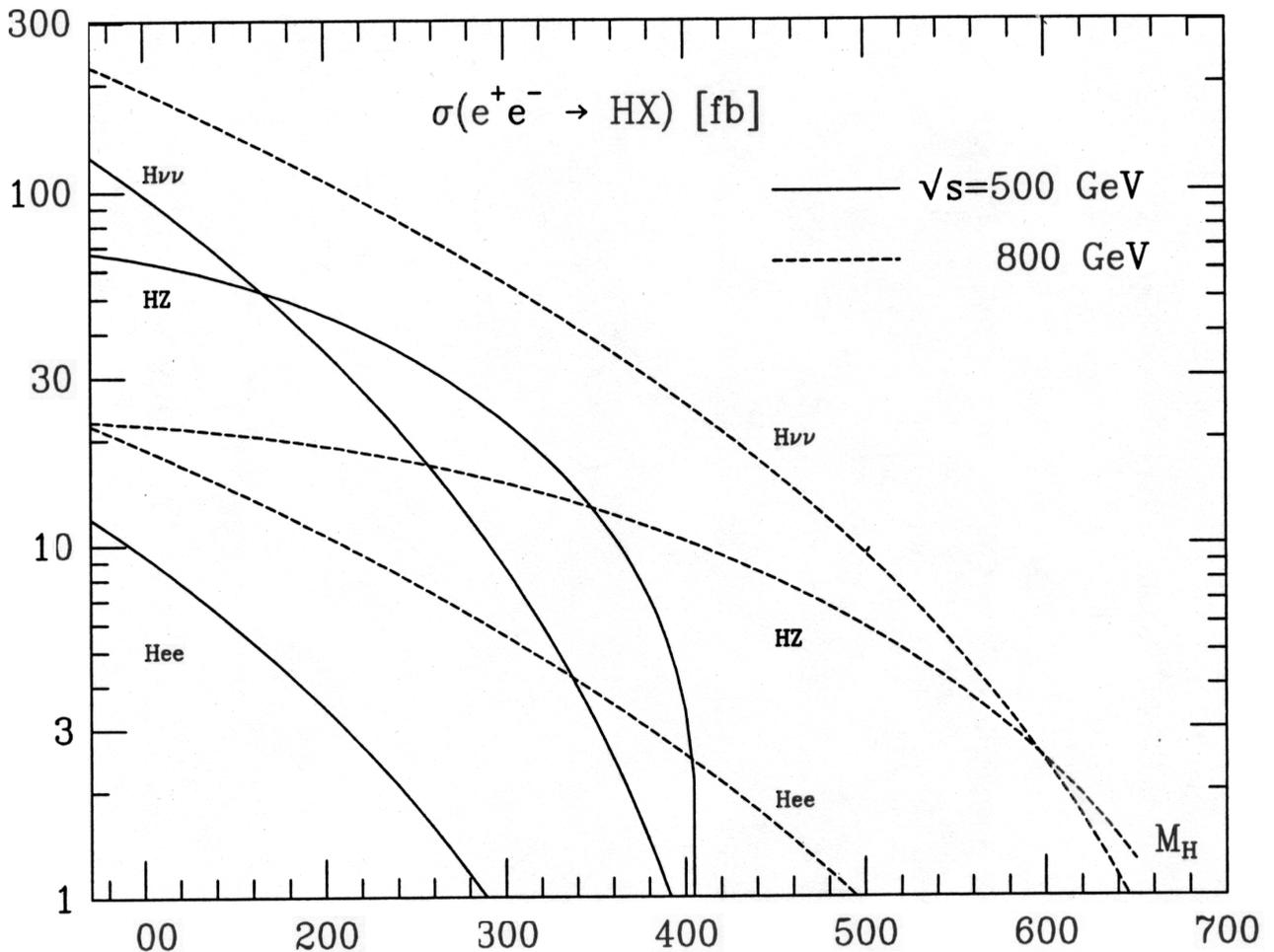


Figure 3: Processes for production of the Higgs boson at an  $e^+e^-$  linear collider.

From J. Bagger et al, The Case for a Linear Collider ..



## Muon Sources - New Physics

SM Higgs	500 GeV			800 GeV		
Final State	$\sigma(\text{fb})$	$\sigma^* \text{BR}_Z(\text{fb})$	$\sigma^* \text{BR}_H(\text{fb})$	$\sigma(\text{fb})$	$\sigma^* \text{BR}_Z(\text{fb})$	$\sigma^* \text{BR}_H(\text{fb})$
$Z H(140)$ $\mu\mu H$	58	2	10	22	0.7	4.0
$H(140) \nu \bar{\nu}$	67		12	150		27
$e^+ e^- H(140)$	6.5		1.2	15		2.7
$H(140) \text{Totals}$	131.5	2	23.2	187	0.7	33.7
$Z H(350)$ $\mu\mu H$	12	0.4	2.2	12	0.4	2.2
$H(350) \nu \bar{\nu}$	3.2		0.6	38		6.8
$e^+ e^- H(350)$	0.4		0.1	3.9		0.7
$H(350) \text{Totals}$	15.6	0.4	2.9	53.9	0.4	9.7

\*BR of H to one or more muons  
for H(140), ignoring  $Z \Rightarrow b\bar{b} \Rightarrow \mu$  for H(350), ....

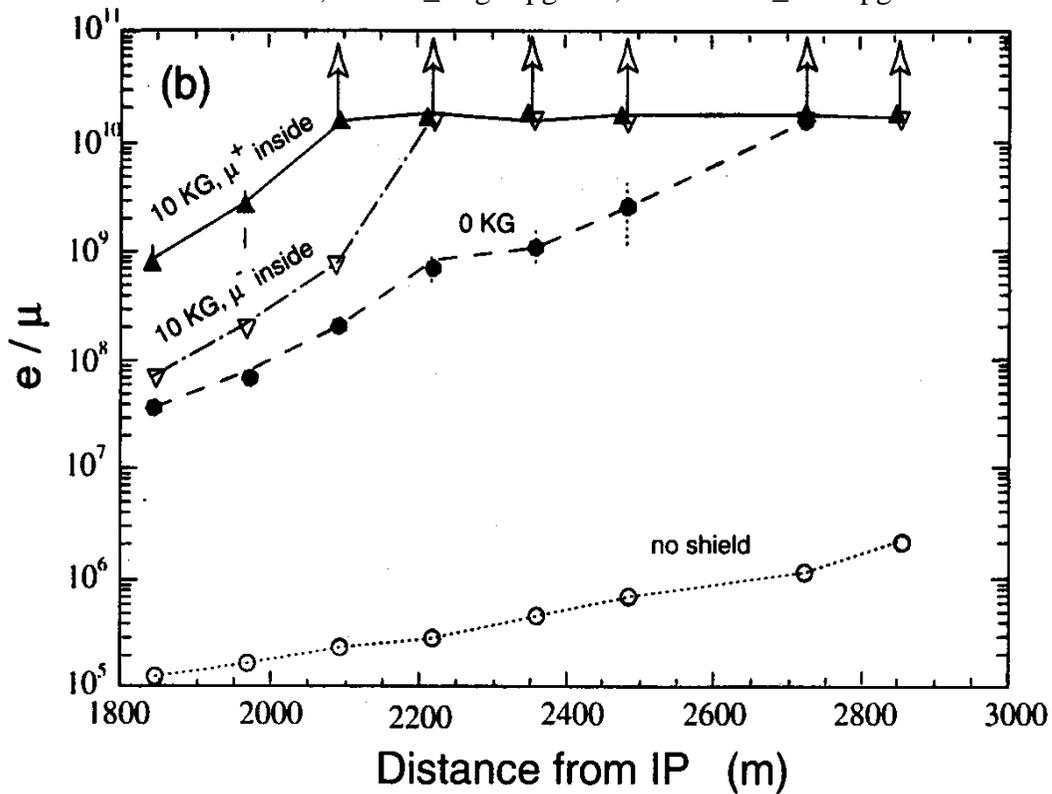
$$\begin{aligned} \text{BR}_H &= \text{BR}(H=WW^*2*\text{BR}(W\Rightarrow\mu)) + \text{BR}(H\Rightarrow b\bar{b}*2*\text{BR}(b\Rightarrow\mu)) \\ &= 0.48*2*(1/9) + 0.37*2*0.1 \\ &= 0.181 \end{aligned}$$

$$\begin{aligned} \text{BR}_H &= \text{BR}(H=WW^*2*\text{BR}(W\Rightarrow\mu)) + \text{BR}(H\Rightarrow ZZ)*2*\text{BR}(Z\Rightarrow\mu) + \text{BR}(H\Rightarrow t\bar{t})*2*\text{BR}(t\Rightarrow\mu) \\ &= 0.68*2*(1/9) + 0.31*2*0.03367 + 0.01*2*0.19 \\ &= 0.176 \end{aligned}$$

Higgs with 1,2 or 3 muons is rare; hundreds/year  
Muon detection must be very efficient.

# Beam Line Muons

T. Tauchi, LCWS\_Sitges pg 811, and LCWS\_2000 pg 107



Collimation using concentric magnetized axial toroids.  
 $B = 10\text{KG}$ ;  $B^+$  for  $1 < r < 10\text{ cm}$ ;  $B^-$  for  $10 < r < 30\text{ cm}$ .

$\sim 10^{10}$   $e$ 's/RF bucket with 0.1 - 1% lost in phase-space tails.

Attenuation:

- $\sim 1 \times 10^5$  - No shield
- $\sim 3 \times 10^7$  - Collimation ( $x, y, p_x, p_y$ ) w/o B
- $\sim 10^9 - 10^{10}$  - Collimation w B

Also will attempt to eliminate phase-space tails at 8 GeV.

Expect  $< 1$  to  $10$  beamline  $\mu$ 's per pulse.

# Muon Rate Summary

One year ( $10^7$  s) at  $10^{34}$   $\text{cm}^{-2}$   $\text{s}^{-1}$  is  $100\text{fb}^{-1}$ .

- Conventional sources of muons:

$$2 \text{ pb} * 100\text{fb}^{-1} * 50\% \text{ eff.} = 100\text{K events.}$$

- New Physics: Higgs  $\Rightarrow$  muons

$$25 - 50 \text{ fb} * 100\text{fb}^{-1} * 50\% = 3 - 5 \text{ K events}$$

- Beamline Muons: Assume  $1\mu$  for each  $10^{12}$  electrons.

NLC: 190 pulses w/  $0.75 \text{ E}10$  e's/pulse in  
266 ns  $\Rightarrow$   $1.46 \mu$ 's per train.

JLC: 72 pulses w/  $1.1 \text{ E}10$  e's/pulse in  
202 ns  $\Rightarrow$   $0.8 \mu$ 's per train.

TESLA: 2820 pulses in 0.95ms  $\Rightarrow$  29 pulses  
in  $10\mu\text{s}$  w/  $2\text{E}10\text{e's/pulse}$ ,  $\Rightarrow$   
 $0.58 \mu$ 's per  $10 \mu\text{s}$ .

# R&D Topics: Physics & Backgrounds

We need to look at:

- Muons from interesting sources:

$c\bar{c}, b\bar{b}, t\bar{t}, W^+W^-$

Overlap with physics groups:

Higgs (VanKooten),

Top (Gerdes),

W pairs (Barklow)

SUSY e.g. Smuons (Nauenberg)

Not competition, but to make sure the muon system can do what is required. (efficiencies, etc.)

- Muon backgrounds from linac, IR, and  $u, d, s$  decays

- Compilation of what is known/needed. X

# Simulation Help

In addition to Norm Graf et al at SLAC, there is local help for generating event samples: NICADD (No. Ill Center for Accelerator & Detector Development).

Muon Detector Simulation Personnel:

David Hedin  
Arthur Maciel\*  
Rob McIntosh

Recently joined: Caroline Milstene

# Muon System Specifications

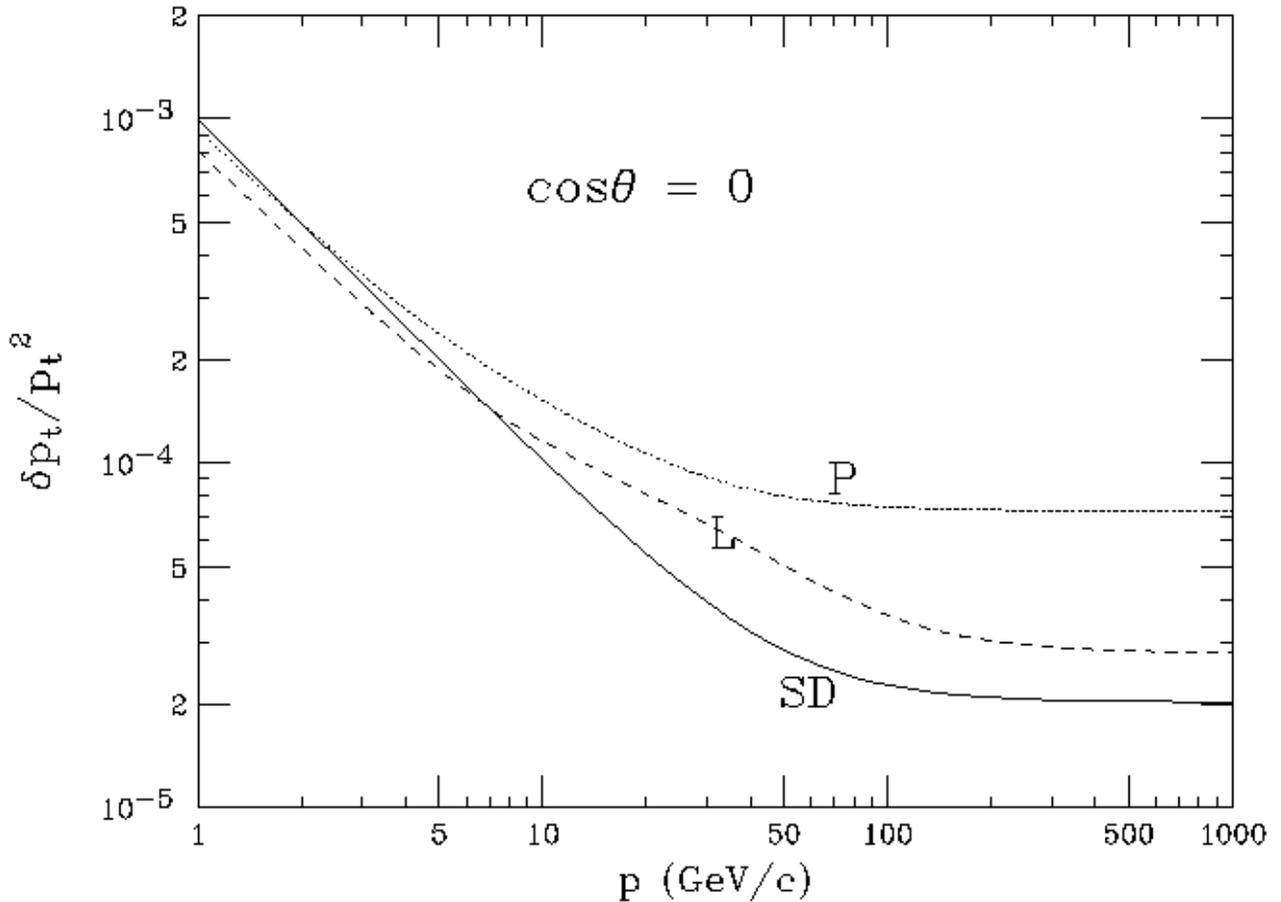
- Muon **Identification** by penetration through **12 - 14  $\lambda$** .
- Muon **Charge** & precise **Momentum** from central tracking.
- Muon **Tracking** and **Link-up** with cent. tracking: **~15 hits**
- **High Tracking Efficiency**.
- **Tail-catcher Calorimeter**.
- **Must identify conventional and new physics muons and background muons from the beams and cosmic sources.**

## Candidate technologies:

(1) Resistive Plate Chambers

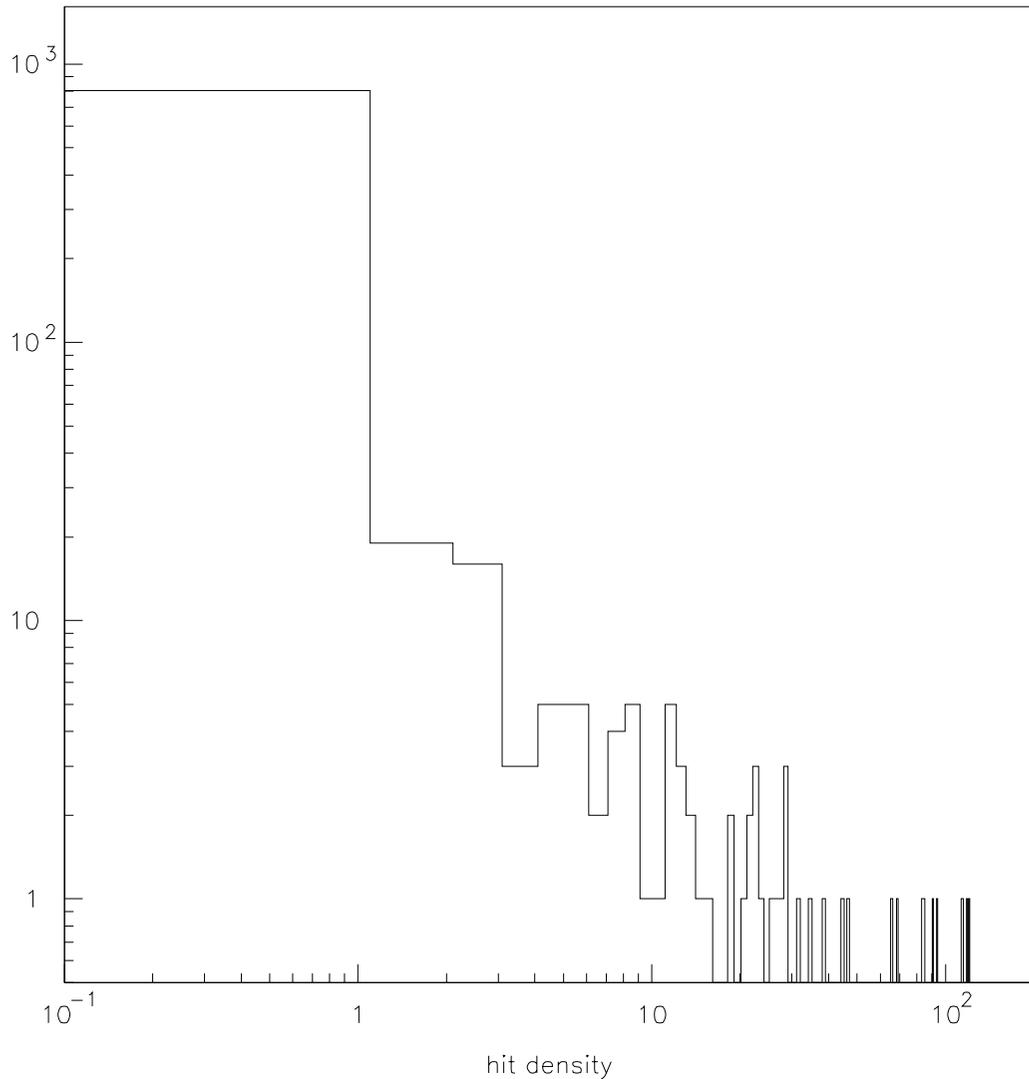
(2) Scintillator Based Detectors

# Central Tracking Momentum Resolution



From: "Detectors for the Next Linear Collider"  
ed. J. Brau et al; Snowmass 2001

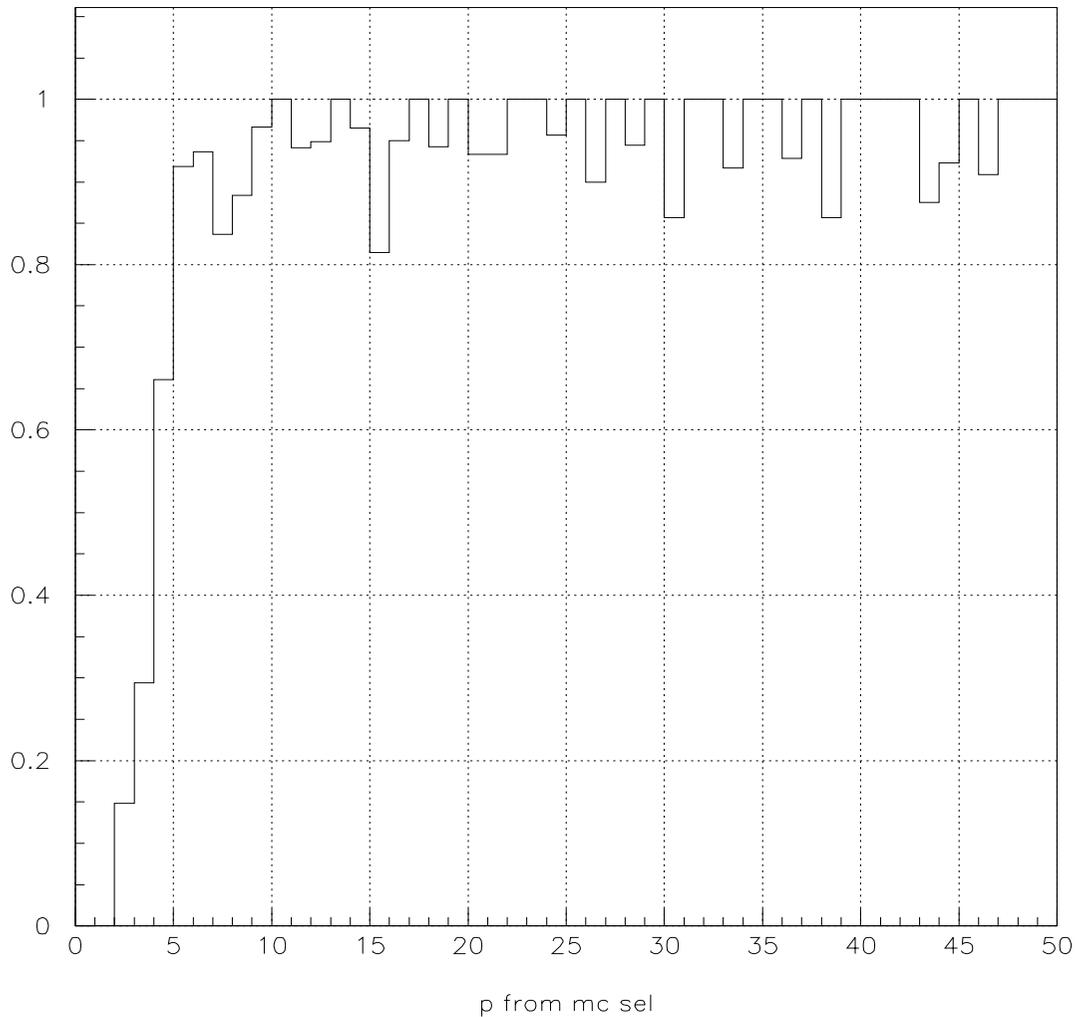
# Hit Density for b b Events



Max. hit density (/sq. cm)

From TESLA Design Report - M. Piccolo et al

# Efficiency vs. Muon Momentum

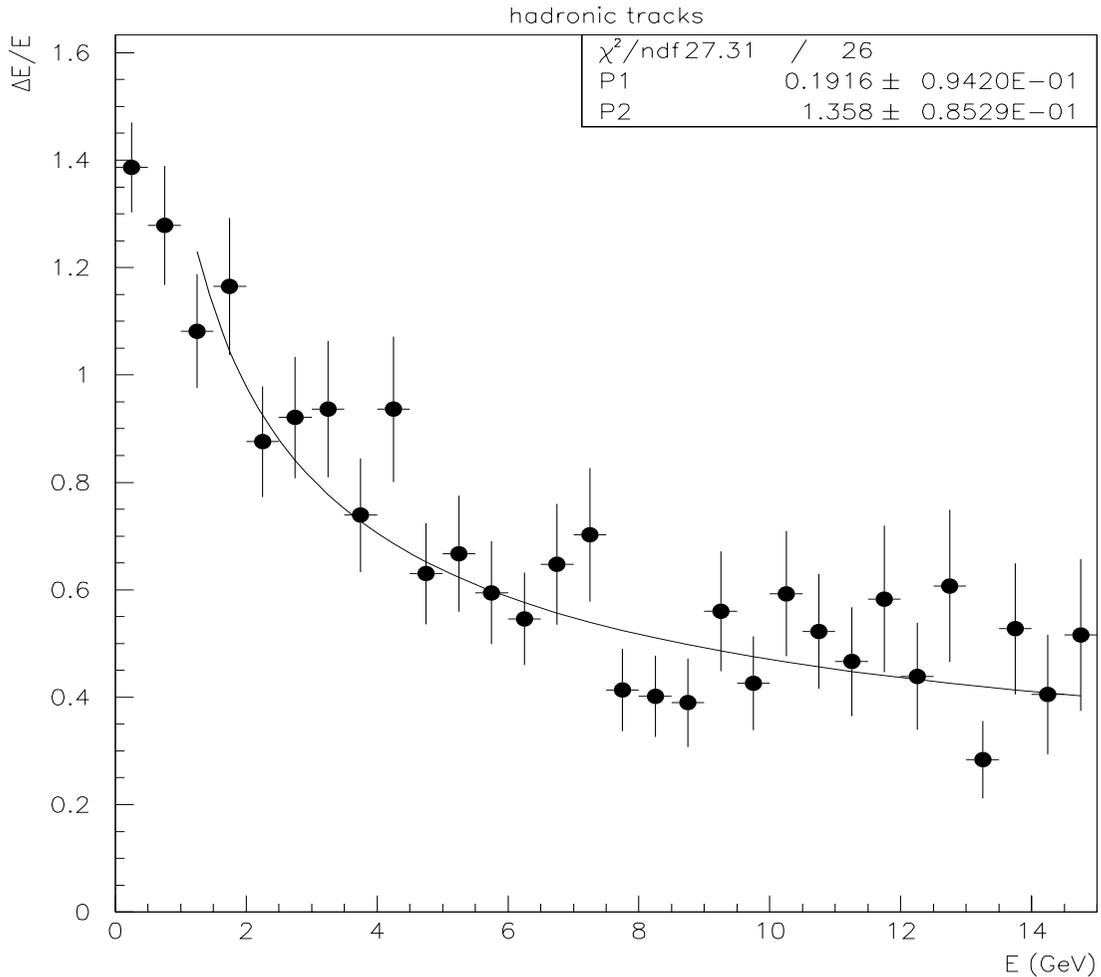


Monte Carlo Muon Momentum

From TESLA Design Report - M. Piccolo et al

# Leakage Hadronic Energy Resolution

From: TESLA Design Report - M. Piccolo et al



Calorimetric Energy for Hadrons Entering the Muon System

# Scintillator Based Muon System

- Why scintillator?
  - Backup calorimetry needed. Cal depth is:  
3.2  $\lambda$  , 5.4  $\lambda$  , 6.7  $\lambda$  for NLC(P), TESLA, NLC(L)  
Example from Dishaw et al
  - Demonstrated technology. Robust.  
Used in many neutrino expts for  $\mu$ 's & h's.  
MINOS, e.g.
  - Detectors can be calibrated:  
LED pulser plus initial beam tests.
  - With scintillator strips,  $\mu$  's can be tracked.
  - The precise measurement of  $p_\mu$  is done via central tracking.
- Proposed Layout
  - 16 - 5cm gaps between 10cm thick Fe plates.
  - Module sizes: 940(L)X(174 to 252)(W)X1.5 cm<sup>3</sup>.
  - 4.1 cm X 1 cm extruded scint.: 8u & 8v planes.
  - Light output from both ends: 11(n) + 6(f) p.e.s.
  - Use multi-anode PM; 94K fibers X 2 channels?
  - Expect  $\sim 1/\square E$  for calorimetry.

# Sampling Calorimeter

E379 P. Dishaw Thesis SLAC-216

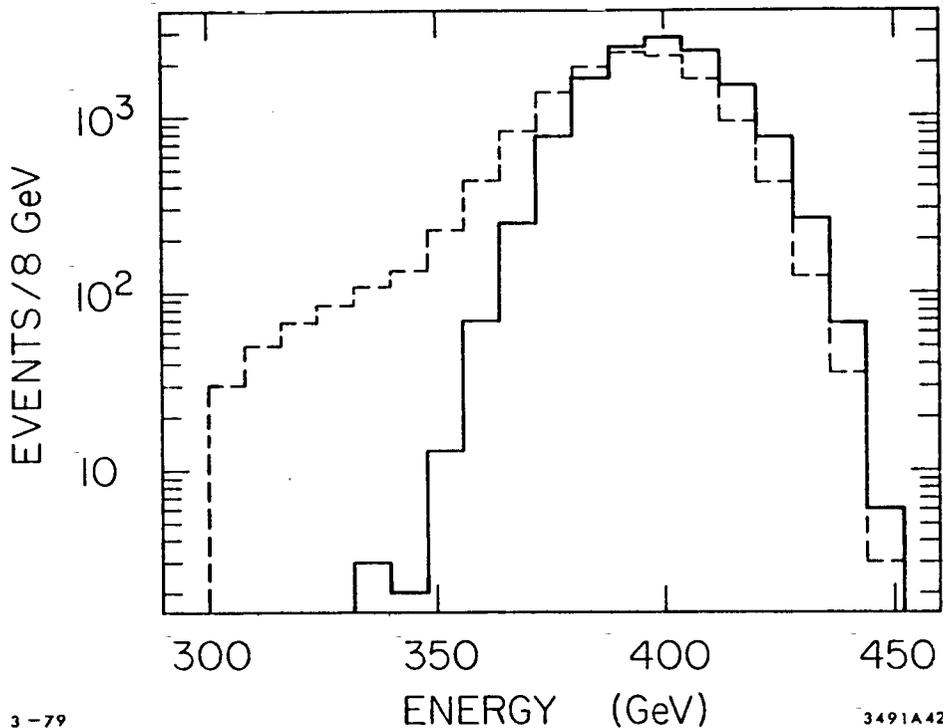


Fig. 39 Calorimeter measured energy for the full calorimeter (approximately 3 meters) (solid histogram) and the same distribution for a calorimeter consisting of only the first 30 plates (approximately 1.3 meters) (dashed histogram, arbitrarily cut off at 300 GeV). Non-containment in the second case leads to nonGaussian behavior in the low side of the measured energy.

## Fe & Plastic Scintillator 30" H X 30" W

Plates: 1 - 20 1.5" Fe  
 21 - 45 2" Fe  
 46 - 49 4" Fe

$$\sum_{i=1}^{30} C_i, \frac{\sigma_{30}}{E} = 6.38\%$$

$$7.58 \lambda$$

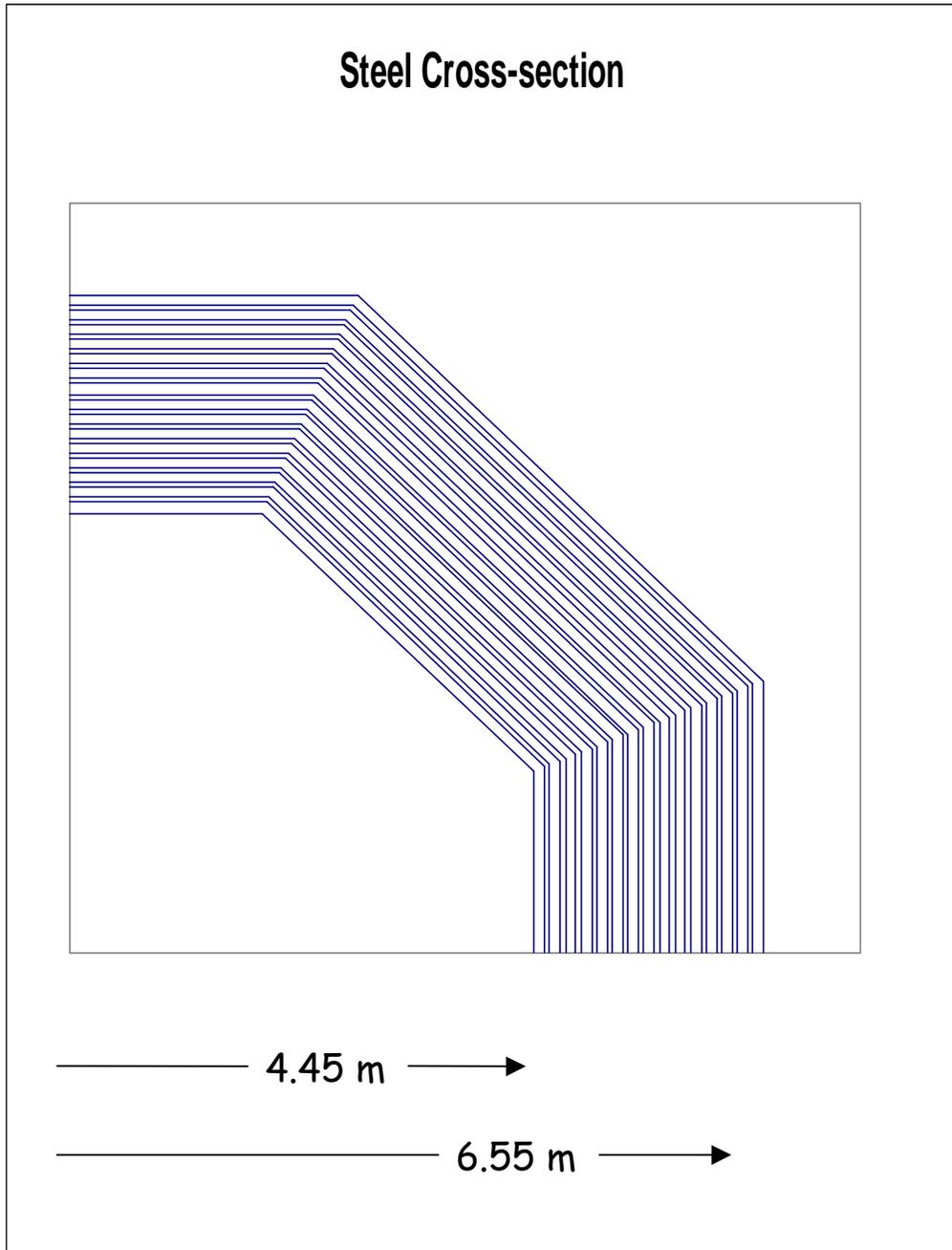
$$\langle E \rangle = 389 \text{ GeV}$$

$$\sum_{i=1}^{49} C_i, \frac{\sigma_{49}}{E} = 3.63\%$$

$$11.52 \lambda$$

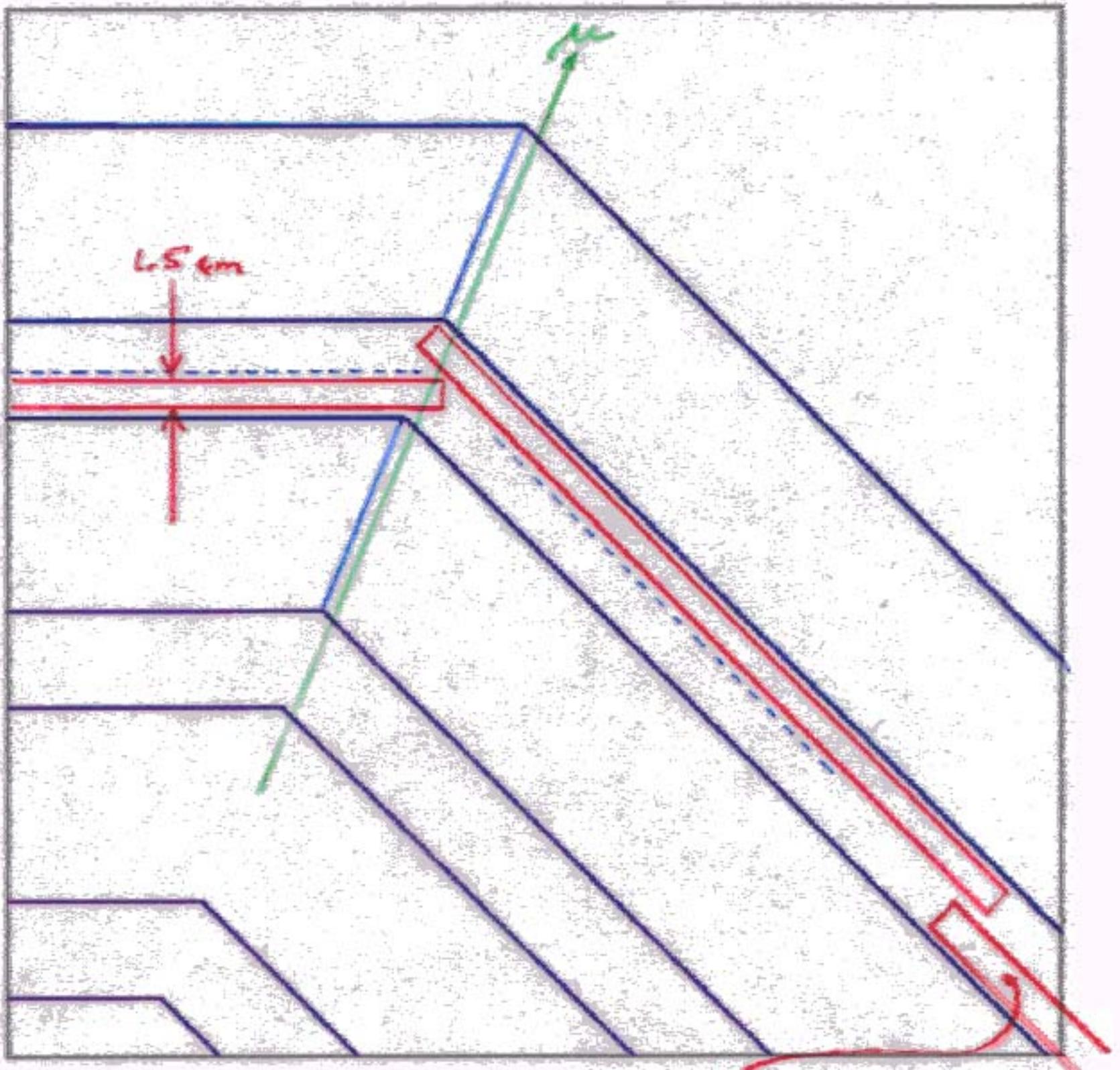
$$\langle E \rangle = 400 \text{ GeV}$$

# Steel Cross-section



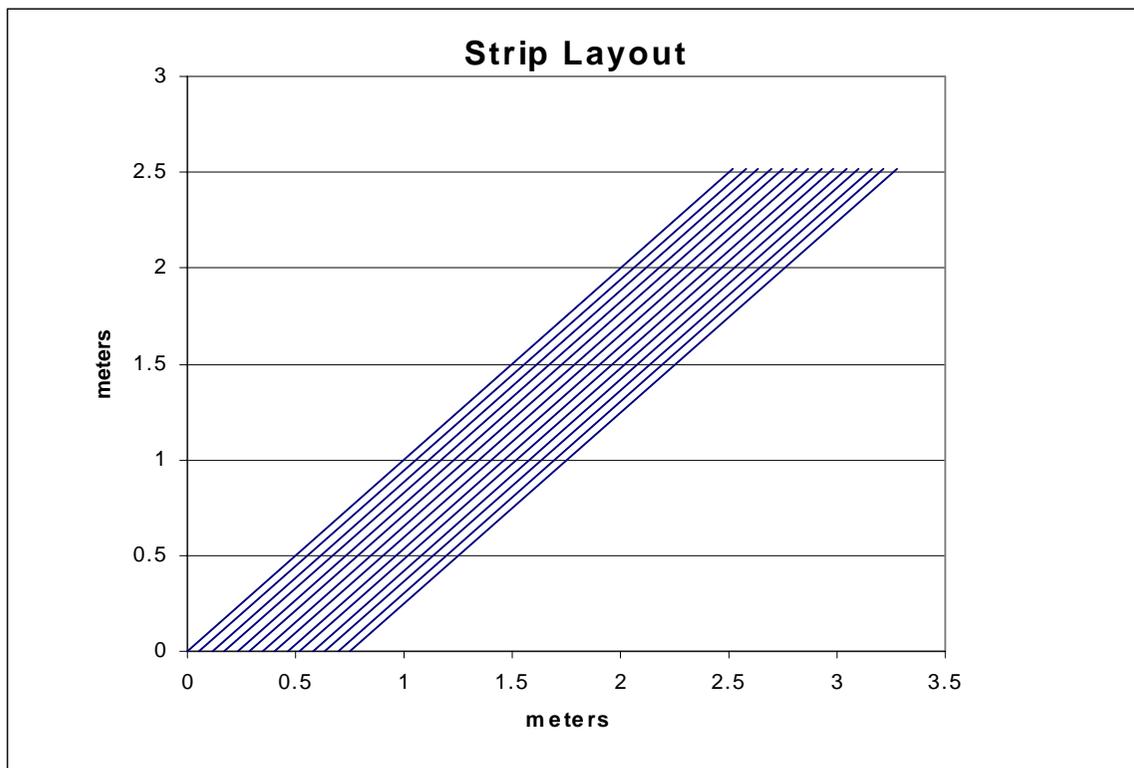
Fe thickness = 10 cm, Gap = 5 cm

# Steel Cross-section

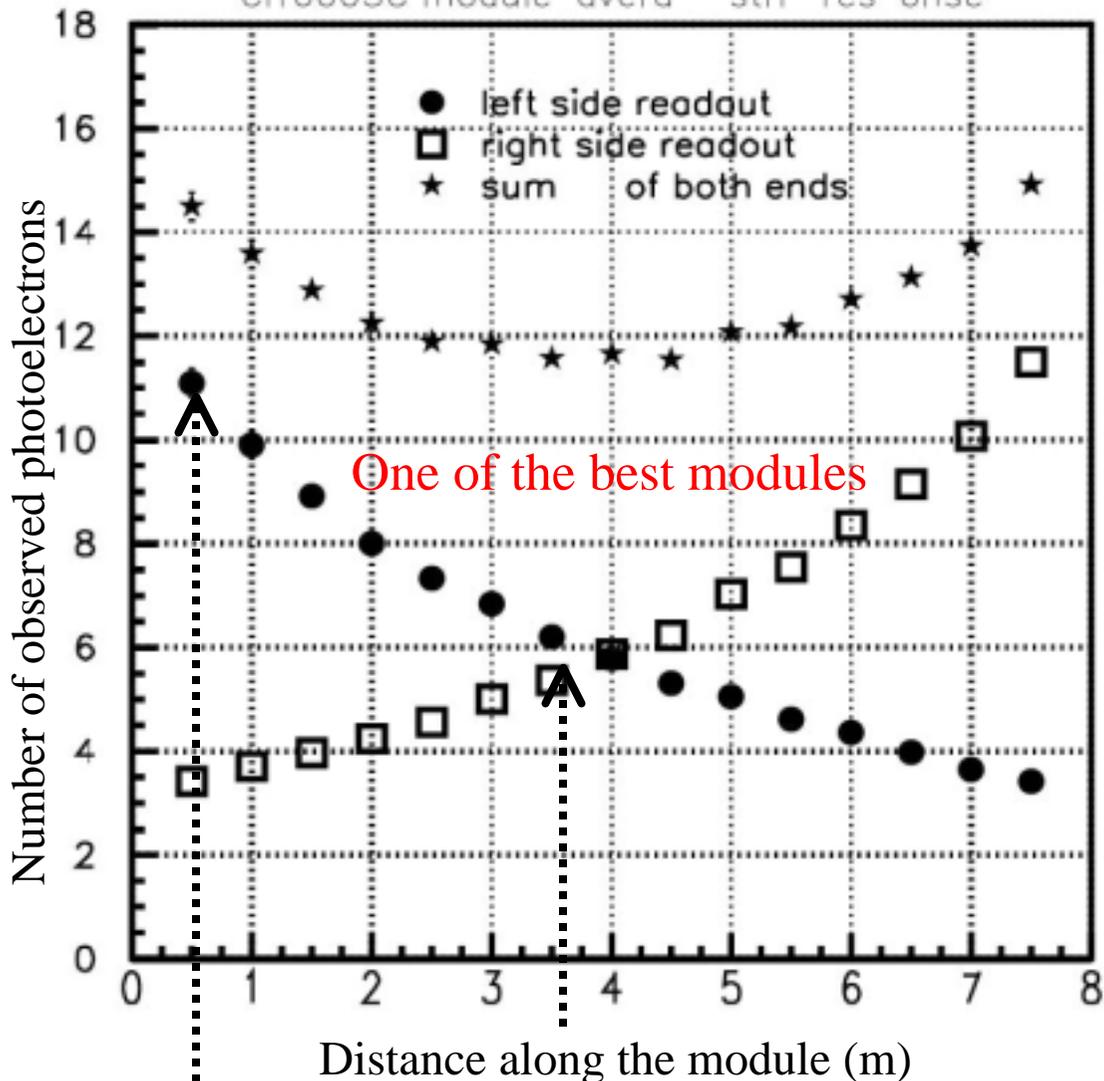


Two modules  
per gap.

# Scintillator Layout u and v strips



# MINOS Scintillator



Q.E.  
13.5%

Near  
 $11 \pm 3$  p.e.s

3.6 m

Far - proposed geometry  
 $6 \pm 2$  p.e.s

Light output using the full MINOS apparatus:  
Connectors, clear fibers, multi-anode PMTs, ...

# R&D Issues

- Mechanical (w. K. Krempetz)

Fe structural engr; constr. techniques; muon plane supports; cable routing; impact on other systems; installation issues. (X)

- Muon Software (w. D. Hedin, A. Maciel)

Muon detector tracking and link-up with central tracking.

Shower leakage into muon detectors. (w. A.M. , C.M., Marcello Piccolo INFN)

Sampling calorimeter and Energy Flow algorithms: e.g.  $\langle E_{jet1} + E_{jet2} \rangle$  comparison. X

Is  $4.1 \times 1 \text{ cm}^2$  the optimal scint. cross-section? (A. Para, X)

Muon detector Web page development. X

# R&D Issues (cont.)

- Muon Detector Planes

Scintillator design, specs, prototype extrusions using Fermilab machine.

(A. Bross, NICADD, X)

Prototype detector plane engr., R&D proposal, construction (J. Blazey, G. Fisk, + X)

Fiber specs, fiber routing, bending, fiber guides/molds. Two fiber OR. (A.B., NICAAD, X)

Quality checks - mechanical, meas. w. radioactive sources, test electronics. X

- Electronics/Cosmic Ray Test Stand

PM Specs, PM tests & selection, FE electronics (10 p.e.s), CR => LC detector?

Small DAQ sys., Test scenario (NIU, X)

# R&D Issues (cont.)

## Test Beam

A proposal is needed for a 120 GeV/c test beam from the MI. X

Muon prototype detector tests with Fe + scint. planes (full width, shortened length) to understand system issues including backgrounds from jets, software, calibration, participation with other detectors. X

Such a facility would provide an opportunity to different technologies and thereby provide input for decisions on detector design issues.

Examples: Energy flow software/algorithm development with prototype detectors; calorimetry, muon, electronics tests

# Channel Count, etc.

	Barrel	Ends	Total
Fibers	51,200	42,766	93,966
Channels			187,932
Scintillator			
Area (m <sup>2</sup> )	7,174	4,353	9,527
Vol. (m <sup>3</sup> )			95.3
M ( $\rho=1.2\text{g/cm}^3$ )			114.3Tm

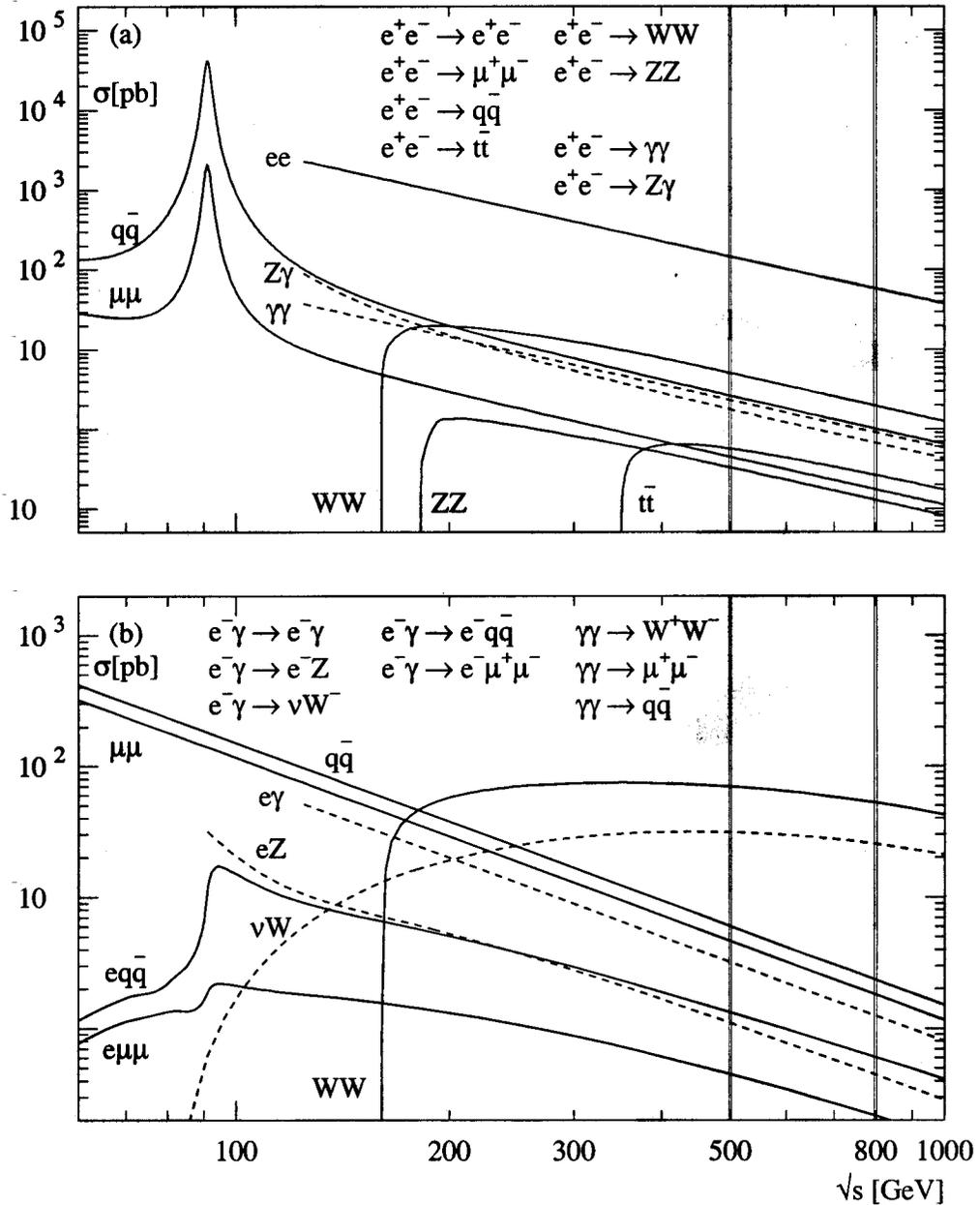
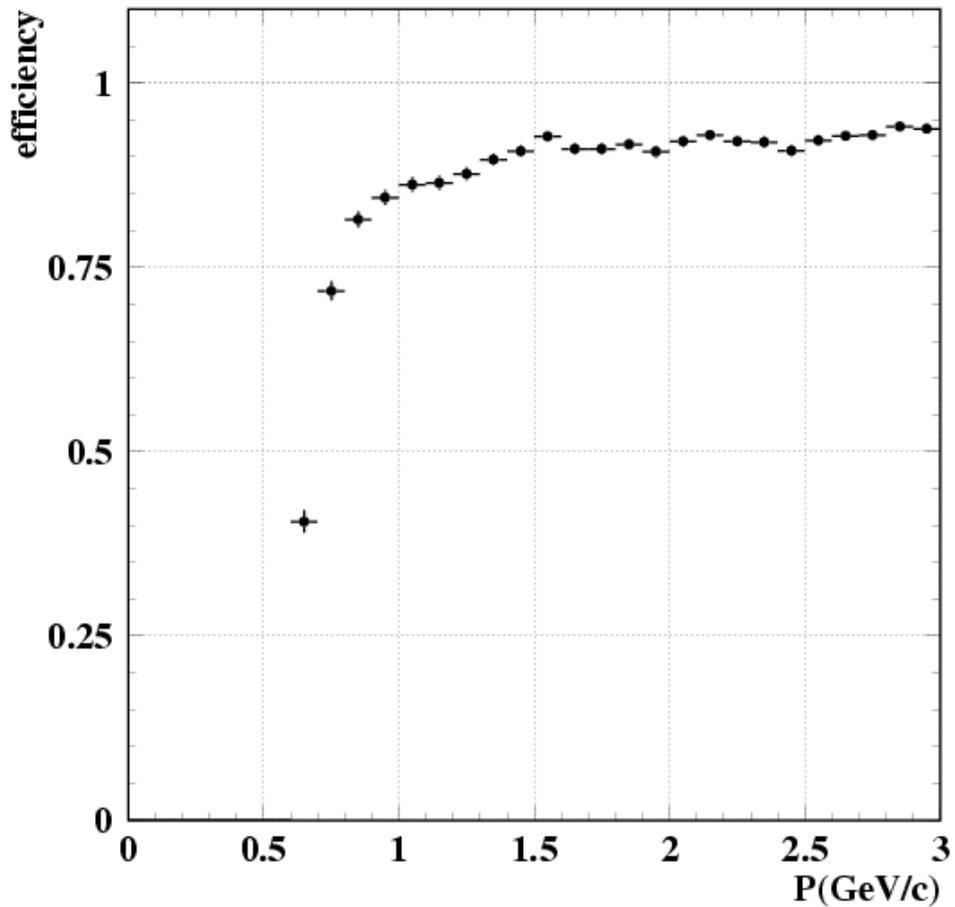


Figure 1: (a) The basic processes of the Standard Model:  $e^+e^-$  annihilation to pairs of fermions and gauge bosons. The cross sections are given for polar angles between  $10^\circ < \theta < 170^\circ$  in the final state. (b) Elastic/inelastic Compton scattering and  $\gamma\gamma$  reactions.  $\sqrt{s}$  is the invariant  $e\gamma$  and  $\gamma\gamma$  energy. The polar angle of the final state particles is restricted as in (a); in addition, the invariant  $\mu^+\mu^-$  and  $q\bar{q}$  masses in the inelastic Compton processes are restricted to  $M_{inv} > 50$  GeV.

# Efficiency for BELLE RPC's



From the BELLE Website:

<http://beauty.bk.tsukuba.ac.jp/belle/nim/total/node88.html>